Arctic Mixed Layer Dynamics and Graduate Student Support

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LONG-TERM GOALS

Our long-term goal is to understand the dynamic and thermodynamic processes causing changes in the velocity and density structure of the upper Arctic Ocean. For example we seek to understand the heat and mass balance of the mixed layer. In light of recent changes in the upper ocean structure, our long-term goals are shifting toward processes important to larger-scale changes.

OBJECTIVES

Presently our primary objective to understand the effect of horizontal inhomogeneity on the surface boundary layer during summer.

APPROACH

In studying horizontal inhomogeneity in the upper ocean we have developed a technique to measure vertical water velocity and the turbulent fluxes of heat and salt with Autonomous Underwater Vehicles (AUV), and constructed the Autonomous Micro-conductivity and Temperature Vehicle (AMTV) to fully test and exploit the technique. AMTV data was gathered at the Surface Heat Balance of the Arctic (SHEBA) station in 1998 and shows the effects of horizontal inhomogeneity on mixed layer fluxes around a summer lead. We are modeling these effects with a modified time-varying 1-D model and a more sophisticated time-varying 3-D model.

WORK COMPLETED

The last step in development of the Kalman smoothing method for measurement of turbulence was completed with the publication of our paper (Hayes and Morison, 2002) in the *Journal of Atmospheric and Oceanic Technology*. It is in the May 2002 issue.

To understand the observed summer lead phenomena, our graduate student, Dan Hayes previously simulated steady, two-dimensional (x and z), forced convection using a simple advective transformation ($x=V_{ice}\, t$). This converts the problem to a one-dimensional (z) time-dependent problem. The method accounts for spatial variability due to growing boundary layers. In this the model was able to simulate some of the key boundary layer behavior observed during SHEBA with the AMTV. However, because it is not truly two-dimensional, the model does not take into account the effects of horizontal pressure variation or allow for the propagation of horizontally inhomogeneous initial conditions. Therefore, the model was not capable of simulating the flushing of a preexisting freshwater lens from a lead or the potential for instability due to the action of vertical velocity shear on such preexisting lenses. Consequently, most of Hayes's effort on this grant over the past year has been devoted to developing a more sophisticated model of summertime lead convection.

Hayes has been working on a 3-D model based on that originally developed by David Smith of Arizona State University. Hayes has been fine tuming the model to accurately simulate two periods during SHEBA. One period saw a pre-existing lens of warm, fresh water in the lead mix away over a period of a few days. The other period was a quasi-steady environment in which fresh water was continuously entering the ocean through leads and being rapidly mixed in the turbulent boundary layer. The ice velocity was higher in this period.

Certain improvements to the model were necessary before these periods could be simulated. Model improvements include an ice topography boundary condition. This is an arbtrarily shaped top boundary where velocity and salt flux are zero, while temperature is constant. It allows us to simulate for the first time the confinement of a freshwater pool by the walls of the lead. Hayes has also included a predictive equation for temperature, a radiative flux over the lead that decays exponentially with depth, and changes to the salinity equation and equation of state to use salinity deviations (improves truncation error). Finally, McPhee's First Order Closure technique for calculating eddy viscosity (McPhee, 1994) has been implemented. In this closure scheme, eddy viscosity is allowed to change in depth and time.

RESULTS

Many 3-D runs have been completed for both periods at SHEBA. So far the model domain and lead size have been kept relatively small (O[100 m]). Results for both the initial flushing case and the steady flux case are reasonable, with freshwater flushing under the downstream edge of the lead and setting up vertical temperature gradients downstream of the lead in qualitative agreement with our measurements. For example with this model we find that downstream from the lead edge, temperature profiles are such that heat diffuses both upward and downward away from region of temperature maximum a few meters below the ice. The results also show that unstable regions occur at the downstream edges of leads soon after the fresh water flux at the lead surface begins. The realistic ice topography implemented in the 3-D model is crticical here. Not only does the topography allow the model to begin with a quiescent pool of fresh water in the lead contained by the surrounding ice, it appears that downstream ice topography is necessary for the instabilities to occur. Shear in the water column in the lee of large topographic features carries salty water from downstream over fresh water flushing out of the lead. Where this occurs, patches of unstable stratification appear.

IMPACT/APPLICATIONS

Impacts of this research include providing a technique whereby nearly any AUV can provide turbulence data as a side benefit to other sampling it carries out. Used with simple vehicles, the technique will yield spatial maps of turbulent energy. Used with sophisticated AUVs, the technique will also yield spatial maps of vertical fluxes of the other variables being measured. Such maps will be the keys to identifying dynamically critical areas and determining the budgets of heat, salt, biomass and pollutants. Modeling the effects of horizontal inhomogeneity will produce fundamental knowledge needed to model the dispersion of moisture, heat, and chemical agents from point sources in the atmosphere as well as the ocean.

TRANSITIONS

Vehicles like the AMTV and the Kalman smoothing technique could be used militarily. Such AUVs could make clandestine surveys of littoral areas. The method of extracting information on water motion from vehicle motion would have application in determining the wave energy in areas of planned amphibious assault. The technique may also find application as a non-acoustic detection and tracking tool. This would find application in "smart" and acoustically quiet weapons that could detect the wakes of vessels and follow them. Torpedoes using the technique in real time could conceivably follow turbulent ship wakes to their targets.

RELATED PROJECTS

REFERENCES

Hayes, D. R., and J. H. Morison, 2002, Determining turbulent vertical velocity and fluxes of heat and salt with an autonomous underwater vehicle, in press, *J. Atmos Ocean. Tech., 19* (5), pp. 759–779.

McPhee, M. G., 1994, On the turbulent mixing length in the oceanic boundary layer, *J. Phys Oceanogr., 24*, 2014-2031.

PUBLICATIONS

Hayes, D. R., and J. H. Morison, 2002, Determining turbulent vertical velocity and fluxes of heat and salt with an autonomous underwater vehicle, in press, *J. Atmos Ocean. Tech., 19* (5), pp. 759–779.